MEASUREMENT OF FORCE DISTRIBUTION ALONG THE EXTERNAL TENDONS

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Abstract

These paper deals with monitoring of force distribution along the external tendons. Tendons of capacity 18x0,6” in case of Monostrand application, are often stressed using strand by strand stressing. Variation of position of Monostrands in cross sections of tendon and deflection of tendon in deviators and crossbeams, increase friction losses during stressing. For this system and technology of stressing is very important to know the real loss of prestressing forces during stressing operation particularly when stressing is done in the cold weather time. For measurement of force distribution along the external tendons were applied magnetoelastic sensors PSS125. Precise estimation of the friction coefficients required continuous force measurement during the whole stressing work and appropriate mathematical processing.

Keywords: External cable, friction coefficient, prestressing, stress measurement

1. Introduction

In 2006 has Doprastav, a.s. developed and put into the construction a new innovative type of precast segmental bridge called PDK. The first type of PDK segmental bridge was putting in service in 1992. Up to now there are in operation 5 viaducts with 5 and more spans built by this system. The innovation concerned mainly to:

- Unification of grouted and external tendons to the capacity of 18x0, 6”
- Increasing of external tendons efficiency by changing their longitudinal geometry
- Improving some details on concrete structure like deviators, crossbeams and so.

External tendons remain on the same construction as before the innovation. Unbonded MONOSTRANDS inserted in HDPE (high density polyethylene) pipe dia. 125 mm are grouted with cement after strand by strand stressing, using the single strand prestressing jack. Tendons are anchored with Dywidag anchorages type MA 6819. The main advantage of this tendon construction is possibility to do assembly and stressing in cold weather and to do grouting later. For this new system and technology of prestressing is very important to know the real loss of prestressing forces during stressing operation particularly in the cold weather time.

To estimate reliable values of the friction coefficients μ (in bending) and k (in the straight length) an experimental measurement on cables VK25-23L and VK25-23P was performed. Six EM (elastomagnetic) stress sensors were installed on each cable during its assembly according *Fig.1*. EM sensors were designed as an integral part of the HDPE protecting tube (*Fig.2*).

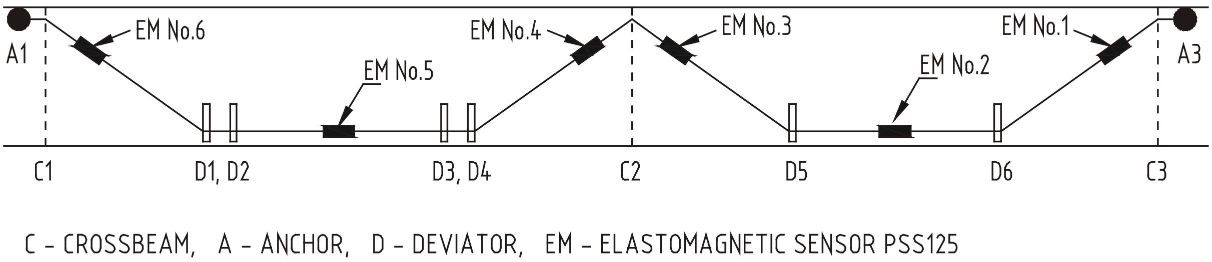

Fig. 1 Location of the EM sensors at the external cable

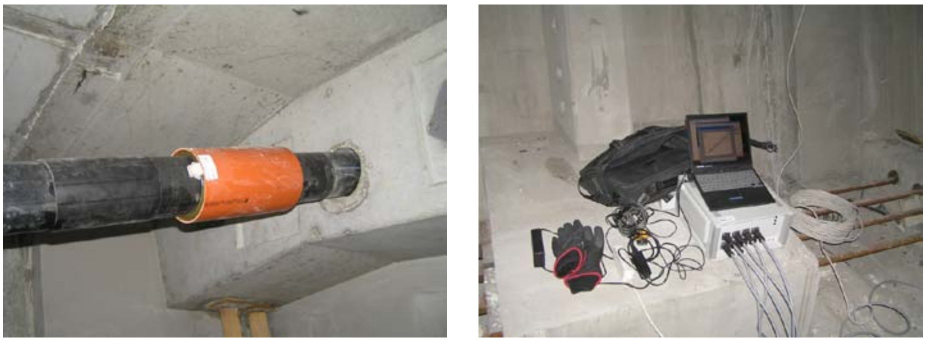

Fig. 2 EM sensor No.4 and the measuring unit DYNAMAG

Monitoring of prestressing operation on the bridge was carried out in 29.11.07 and temperature inside the bridge was about 0°C.

2. Properties of the external tendon (ET) and stressing operation

External cable is assembled from 18 MONOSTRANDs (breaking stress 1770 MPa, cross-sectional area 150mm2, modulus of elasticity 195 GPa). Designed anchoring stress is 1340MPa (anchoring force on one strand 201kN, total tendon force 3618kN). Typical external tendon (see *Fig. 1*) is anchored in crossbeam C1, passes through four deviators in the first span, crosses the middle crossbeam C2, two deviators in the second span and is anchored in crossbeam C3. Using the single strand jack PAUL TENSA SM 240 the tendons were stressed strand by strand. Basically stressing is executed from both anchorages. After stressing all strands from the anchor A3 the strands are stressed also from anchor A1. During stressing work the elongation are measured on every strand.

3. Estimation of the friction coefficients

Due to our long-time experience [1], [2] expected values of the friction coefficients are relatively low, what requires very precise stress measurement. In this new bridge structure the bending angles of ET are also relatively small from 10° in deviators to 19° in the crossbeam C2. EM sensors enable relative precise measurement of force changes in all six cross-sections of the ET where EM sensors are installed. Precise estimation of the friction coefficients requires continuous force measurement during the whole stressing work and following mathematical processing.

Based on the cable geometry the mathematical model of the ET was written down and solved for the experimentally obtained values of ratios Fi/F2. The force behind the active anchorage was not included due to force loss after wedge setting. The friction coefficients were estimated in MathCAD using function Minerr(x, y).

4. Experimental results

Results of measurement are summarized below at *Fig. 3* – *Fig. 5* and in *TAB. 1* and *TAB. 2*. At the beginning strands were prestressed due to assembly technology at level 10% of the designed force.

At *Fig. 3* the time history of force changes are shown in six cross-sections of the external tendon with the EM stress sensors. At *Fig. 4* forces F3 – F6 are shown as a function of force F2 and slopes of the linear trend lines S3 – S6. *TAB. 1* summarizes friction coefficients estimated for the both cables and *TAB. 2* summarizes forces in all cross-sections of the both tendons after stressing from the anchor A3 and the final stressing from the anchor A1. For verification of the friction coefficients is at Fig. 4. shown the theoretical force distribution along the cable, with calculation based on the estimated friction coefficients compared with the measured forces.

From the *Fig. 4* results that the stress loss due to setting of wedges reaches slightly cross-section F2 (after the first deviation). From *Tab. 2* follows that stressing from the anchor A1 increases even force F4 what confirms the calculated values of friction coefficients.

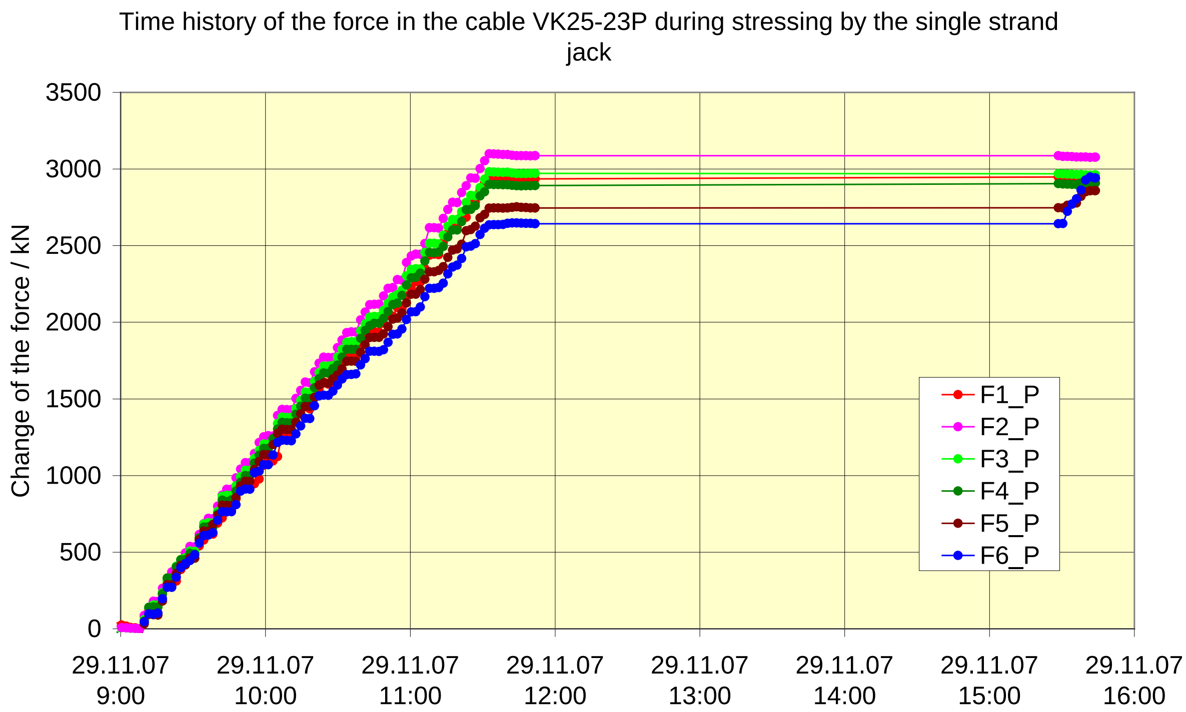

Fig. 3 Time history of force change in six cross-sections of cable VK25-23P during stressing

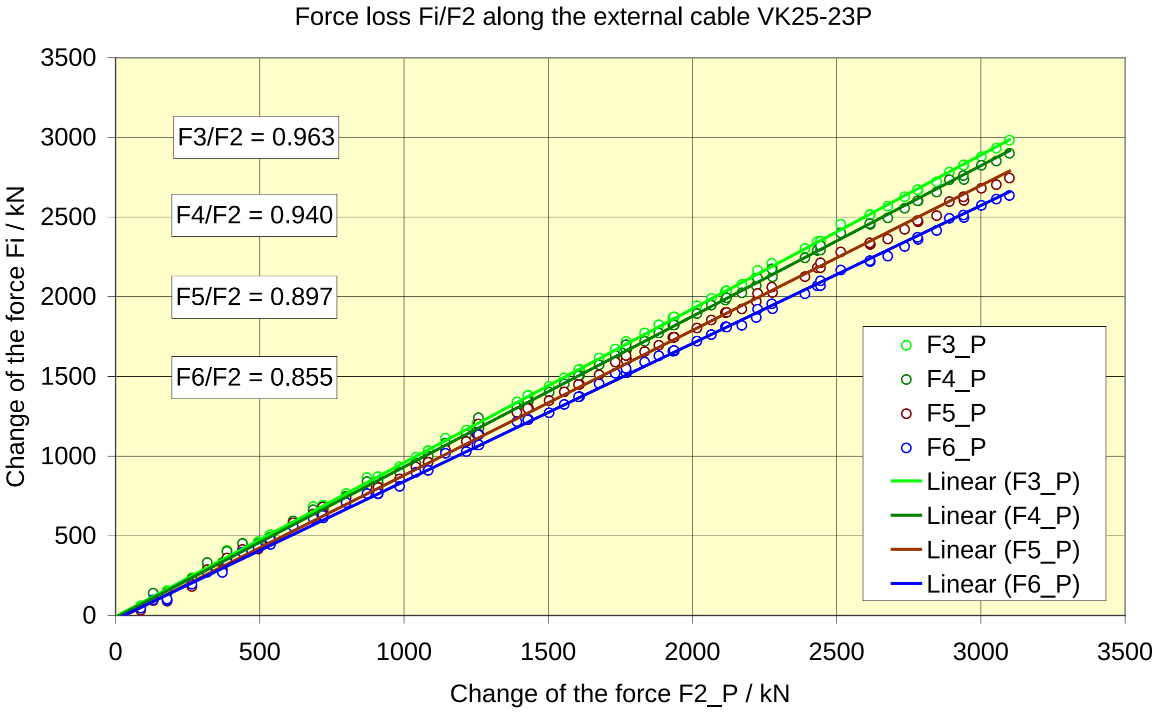

Fig. 4 Slope Si of the linear trend line Fi/F1

TAB. 1 Overview of the calculated values of the friction coefficients

Friction coefficients calculated using measured values of forces Fi and geometry of the external cables VK25-23P and VK25-23L								
	VK25-23P			VK25-23L			sum of the angles / deg	sum of straight lengths / m
Location	Si/S2 linear trendline	Fi / kN	Fi/F2	Si/S2 linear trendline	Fi / kN	Fi/F2		
F1		3294			3308			
F2	1	3429	1	1	3439	1	0	0
F3	0.963	3305	0.964	0.960	3305	0.961	8.738	23.312
F4	0.940	3224	0.940	0.936	3216	0.935	28.059	25.312
F5	0.897	3069	0.895	0.891	3068	0.892	45.105	48.001
F6	0.855	2924	0.853	0.847	2916	0.848	63.565	70.665
Friction coefficients calculated in Mathcad using Minerr procedure							Average	
Friction coefficient **k**	**0.0012**	**0.0011**		**0.0013**	**0.0012**		**0.0012**	
Friction coefficient μ	**0.065**	**0.071**		**0.067**	**0.072**		**0.069**	

TAB. 2 Force distributions along the both cables during stressing

Forces in kN in the locations of EM sensors at the end of the stressing from anchor A3 and consequently from anchor A1.						
EM sensor	F1	F2	F3	F4	F5	F6
External cable VK25-23 P						
Stressed from anchor A3	3294	3429	3305	3224	3069	2924
Stressed from anchor A1	**3280**	**3408**	**3287**	**3234**	**3182**	**3230**
Change of the force / kN	-14	-21	-19	**10**	**113**	**306**
External cable VK25-23 L						
Stressed from anchor A3	3308	3439	3305	3216	3068	2916
Stressed from anchor A1	**3287**	**3431**	**3297**	**3264**	**3243**	**3217**
Change of the force / kN	-21	-8	-9	**49**	**175**	**301**

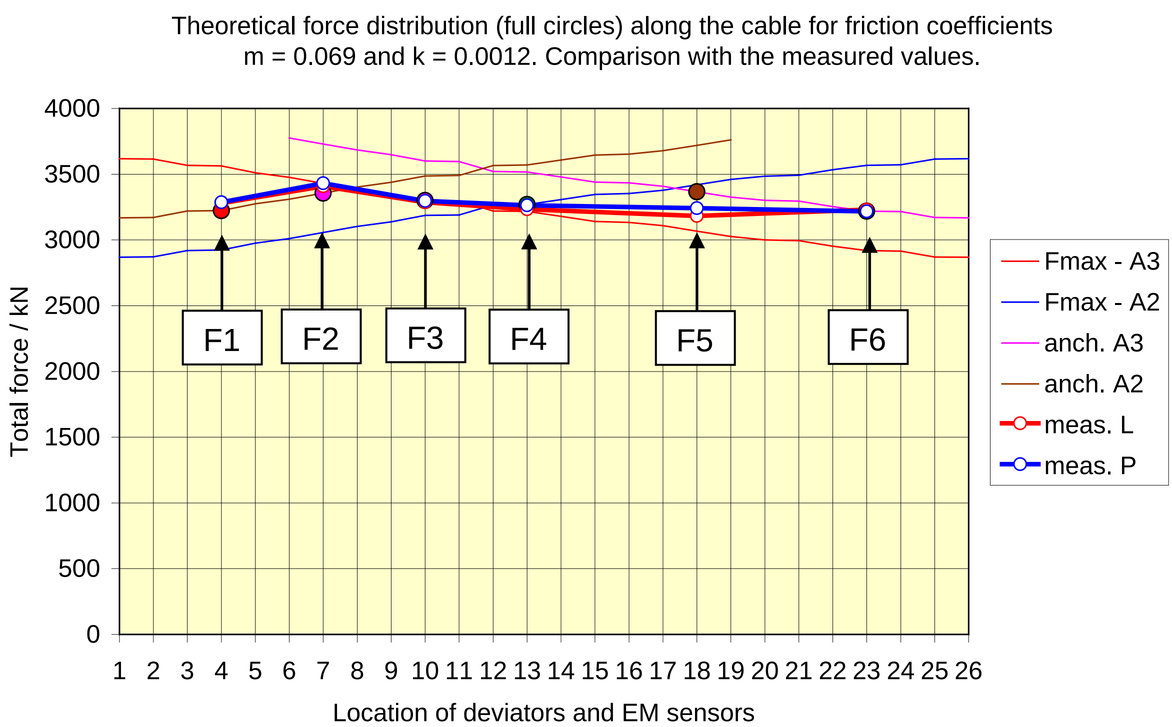

Fig. 5 Comparison of the measured and calculated forces along the cable

Conclusion

The results of measurement of stressing force of two external tendons assembled from MONOSTRAND strands have proven that when stressing strand by strand using single stressing jack it is possible to obtain the effective friction coefficients μ = 0.069 (in bending) and k = 0.0012 (in the straight length). They were attained at temperature of 0°C representing probably the worst case. The grease used with this type of MONOSTRAND shows quite high viscosity at this temperature, the movement of stressing piston was stopped after approximately 1 minute. When stressing at higher temperatures we expect to have lower values of friction coefficients. Influence of friction between the strand and the HDPE sheath was not included in the model of the cable but it affects the effective values of the friction coefficients.

While the measurements of both tendons give same values, they can by reliably used for this type construction of external tendon.

The measured friction coefficients are corresponding also with measurement of losses of prestressing force recently made on the same bridge but different tendons using only 2 and 3 EM sensors. That is why the results can by obtained with greater discrepancy. The friction coefficient $\boldsymbol{\mu}$ (in bending) on tendon with 2 sensors was **0.045.** Measurements were carried out in august at temperature **23°C** of strands. The difference between these two results is caused by different temperature of strand during stressing.

This measurement has also shown how important is to know relationship between friction coefficient and actual temperature of the MONOSTRANDs. The research of this phenomenon will be proceeding in the laboratory conditions this year.

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